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COMPUTER MAPPING
as an aid in
AIR POLLUTION STUDIES

VOLUME TWO: INDIVIDUAL REPORTS

REPORT H
PUGET SOUND REGION STUDY

by

Paul Jack Dangermond

and

John C. Goodrich

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16. Abstracts

A detailed report is presented of the results the Pudget Sound Region Study. An introduction discussing the areas and method of emission estimating, is followed by two sections. The first section duscusses the computer programs and the SYMAP base map. The second section deals with the details involved in the mapping of emissions data. An appendix of computer graphics produced is included.

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LABORATORY FOR COMPUTER GRAPHICS
AND SPATIAL ANALYSIS

Graduate School of Design
Harvard University
Cambridge, Massachusetts

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PREFACE

From July 1, 1968 through December 31, 1969, the Laboratory for Computer Graphics and Spatial Analysis conducted a demonstration of several conceptual, methodological, and technical approaches to problems in the field of air pollution, employing computer-produced maps and allied displays. This work was done under a grant (No. 68A-2405D) from the Division of Control Agency Development, National Air Pollution Control Administration (NAPCA), Public Health Service, U. S. Department of Health, Education, and Welfare.

The results of this study, taken in its entirety, should make an important contribution to the work of Federal, state, and local air pollution agencies, especially in their efforts to determine the best control strategies for use in air quality control regions. The computer is an ideal tool for relating and combining sets of data, and for considering alternatives. For instance, graphic displays can contribute significantly to the evaluation of both short-term and long-term control strategies.

In demonstrating "the use of computer graphics as a means for more clearly portraying data related to the sources, distribution, and community effects of air pollution," the primary emphasis was on case studies for specific areas. The secondary emphasis, to support and complement the case studies, included:

(a) "the development of instructional manuals covering the procedures required for the preparation and interpretation of computer maps of various kinds, as related to air pollution,"

(b) "the use of certain newly developed techniques for describing, analyzing, and portraying quantitative surfaces and movements relative to such surfaces, as related to air pollution," and

(c) "an appraisal of alternative equipment, techniques, and computer programs presently or potentially available for the production of computer graphic displays pertinent to air pollution."

The case study regions were selected in consultation with NAPCA. Considerations included:

(a) sufficient air quality, emission, and related socio-economic and meteorological data--spatially distributed over the region--to enhance the likelihood of adequately demonstrating the mapping techniques;

(b) representative problems in data handling and mapping so that the techniques demonstrated would have applicability to as many other areas as possible;

(c) special problems in data handling and mapping so that as many techniques as possible could be adapted, developed, and tested;

(d) areas of which NAPCA and the individual investigators had special knowledge and could therefore utilize relevant research to enhance the study;

(e) areas where an immediate interest in mapping had been expressed for on-going Federal, state, and local air pollution activities.

Other research was undertaken to support and complement the case studies, and, in particular, to provide:

(a) the widest possible distribution of the mapping programs and accompanying explanation of the techniques through

i) copies of the Laboratory's SYMAP Computer mapping program,
ii) an introductory correspondence course in the SYMAP program,
iii) general program description and supplementary explanation for the existing user-manuals;

(b) a general review of present and potential hardware, output devices, and programs applicable to computer graphic displays of air pollution and related data;

(c) means for predicting, projecting, and correlating air pollution and related data, utilizing the latest

knowledge in planning, geography, and spatial analysis in general;

(d) dissemination of information on approaches and techniques to Federal, state, and local air pollution agencies, especially for use in the air quality control regions.

The final report is divided into two parts: Volume One: Summary, and Volume Two: Individual Reports--the detailed reports on the case study areas and the technical reports related to other research undertaken. The pertinent graphic displays are included with the appropriate individual report and a complete set is provided with the Summary Volume.

Introductory sections describing the air pollution and related data used are provided in the major case study reports for St. Louis and Kansas City; these should be referred to by anyone unfamiliar with the types of data and problems existing in this field. Detailed discussions of special data handling and mapping techniques are presented either as appendices to case study reports, or in separate technical reports.

The Summary Volume includes a discussion of all the areas of research undertaken and contains the complete table of contents for the reports of Volume Two. This should provide a useful reference of the special problems and technical discussions of one report which may be of interest to the reader of another detailed report.

The Puget Sound Region Study is presented here as Report H of Volume Two. It is divided into two sections--computer programs and base map, and mapping of emissions data--in addition to an introduction discussing the areas and method of emission estimating. An appendix of computer graphics produced is included.

The data used in the study was provided by J. A. Kurtzweg and D. W. Weig, through the criteria and standards development program, NAPCA.

This study was under the direction of Paul Jack Dangermond, with the assistance of John C. Goodrich and Kathleen Reine.

The report was prepared by Paul Jack Dangermond and John C. Goodrich.

John C. Goodrich, Editor
Cambridge, Massachusetts
April, 1970

REPORT H
PUGET SOUND REGION STUDY

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1. INTRODUCTION

The Puget Sound study region, located in the northwestern part of the state of Washington, includes the major cities of Seattle, Tacoma, and Everett, and the adjacent urbanized area. The study carried out for this area determined the geographical distribution of motor vehicle emissions for several future transportation and urban development plan alternatives. The study demonstrates an initial step in developing a method for comparing the air pollution implications of alternative land use and transportation plans.

This study is significant because it demonstrates one of the first steps in a relatively simple technique that planning and air pollution agencies can use in the evaluation of various transportation alternatives and their implications. It should be stressed, however, that since only the projected motor vehicle emissions are determined, the technique in its present form cannot be used for meaningful comparisons of alternative land use and transportation plans. Emissions from non-vehicular sources were not determined, nor were any projected pollutant concentrations calculated.

1.1 EMISSION ESTIMATION METHODS[1]

A consistent relationship between the average route speed of a motor vehicle and the quantity of carbon monoxide and hydrocarbons emitted has been indicated by on-the-road sampling from representative automobiles.

Similar speed-emission relationships have not yet been developed, however, for other types of vehicles or for any vehicles possessing emission controls. Thus, at the present time in applying the relationship we must assume no use of control devices and that the automobile speed-emission relationship pertains to all vehicles.

From this relationship were derived power functions indicating the pounds of pollutants emitted by vehicles per mile of travel as a function of route speed. In order to determine total motor vehicle emissions for a zone for a particular time period, we therefore need to know street lengths, average traffic volume, and average zone speed in addition to this power function.

The equation for determining total motor vehicle emissions takes the form

$$E = AX^{b}LV$$

where E = emissions for the zone;
L = length of traffic link;
V = volume of traffic;
X = average vehicle speed; and,
A and b are constants for a particular pollutant in the speed-emission relationship.

1.2 PUGET SOUND STUDY[1]

The Puget Sound area (Seattle, Washington metropolitan area) was used for the first application of the above method since the automobile is the predominant form

of transportation and a significant source of air pollution, and because a recent comprehensive study of alternative transportation and urban development patterns for the year 1985 had been made for the region. This study developed and tested (for their adequacy to meet future travel demands) alternative systems for two land use development patterns. One pattern was basically a continuation of the existing trends in land development (Plan A) while the other was a "Cities and Corridors" concept (Plan B). Emissions were calculated for one system found to have adequate capacity for future travel demand for each of the two patterns. (System 32 for Plan A and System 35 for Plan B). The length, endpoint coordinates, volume of traffic, and average vehicle speeds were determined by the transportation agency for each of the links in the two systems. When this information was utilized in the equation describing the speed-emission relationship, motor vehicle emissions for carbon monoxide, carbon dioxide, and hydrocarbons were calculated and assigned to the midpoints of each traffic link.

2. COMPUTER PROGRAMS AND BASE MAP

The SYMAP program in its present form is limited to 1000 data points per map[2]. In the case of the Puget Sound study over 5500 data points for motor vehicle emissions were generated, and the amount of data was, therefore, incompatible with the data capacity of SYMAP. Because of this it was necessary to develop a new program, appropriately called "Meld," to aggregate the data points.

2.1 GRID MELDING PROGRAM

"Meld"[3] is a program that superimposes a coordinate grid over any pattern or array of data points. The data is then aggregated or averaged (depending upon the type of data employed) into grid cells. The user may input a grid cell size and the program will determine the number of cells, or he may input the total number of grid cells as a constraint and the program will determine the grid cell size.

On the first runs of the program, a constraint of 1000 grid cells was used, and the program determined the grid cell size based upon the extreme points, or locations, of the original data points. The motor vehicle emissions associated with each original data point falling in a particular grid cell were then summed to generate total emissions for each grid cell. By thus allowing the program to select its own grid cell size for the two alternative transportation systems that needed to be mapped, the grid cell size determined by the program

for each system was different, since the original extreme points differed. This allowed for no comparability of the maps because there was no common data coordinate system.

The final solution allowed the data set from the first transportation alternative to be run through the optimizing routine as above, but the grid cell configuration determined for this data set was applied to the data from the other transportation alternative. This produced the common data system which made it possible to examine directly the spatial differences in the alternatives proposed and to map these differences.

After the data bank was manipulated by the "Meld" program it was in a form compatible with the SYMAP data input requirements.

2.2 SYMAP BASE MAP

In creating the Base Map it was thought that there should be special legends to give one a sense of geographic location within the study area. The most distinctive geographic feature of the region is the long broad inlet of the ocean that runs parallel to the coast. The "Sound," as it is referred to, contains a number of islands and a very irregular coastline. This proved to be a good locational identifier and was placed on the map using black line Otolegends. By extending the coastline edges out of the main study region the overall clarity of the map is improved, allowing for more geographic identity of the total region.

Otolegends have the flexibility of being able to retain their relative form and shape even though the map is blown up, or reduced in scale, on successive computer runs. Unfortunately, the black legends are lost in the highest data-level, which also has black symbolism. This could have been avoided by using white legends in the study area and black outside. However, it was decided that black legends should be used throughout the study area because the areas affected by overlapping black symbolism were few in number and small in area, relative to the rest of the map.

Other distinctive features such as lakes, lagoons and islands are also outlined in the black legends. In some cases these legends were done with too much detail, resulting in areas where the coastline is darkened by two rows of legends next to each other. These occurred when the inlets were too narrow to be delineated by legends at the scale employed and should have been generalized.

The Base Map system used[4], as described above, specified the outer boundary of the study area as the outline for the zone to be mapped (or, the area to be "filled" with computer-produced symbolism). Topographic features, including the boundaries of Puget Sound, were specified by legends which do not delineate or affect the zone to be mapped. The result is the inclusion of symbolism over the portions of the Sound contained within the outline. This can give the misleading impression that motor vehicle emissions are being produced in these areas where, of course, no

sources exist (except for the bridges). This impression could have been overcome by specifying that the lowest data level contain only values equal to zero and employing "blank" or white symbolism for these areas.

An alternate approach could have used the boundary of Puget Sound as part of the outline package, thus eliminating symbolism over the water portions of the map. Both techniques of specifying the areas to be mapped have their individual merits, in terms of both analysis and graphic portrayal, but the particular technique employed must be kept in mind when analysis is made of the results in their graphic form.

3. MAPPING OF EMISSIONS DATA

3.1 CITIES AND CORRIDORS PLAN

The first transportation system which was mapped for its pollutant emissions was the "Cities and Corridors" plan. This particular scheme is a comprehensive planning approach for regional transportation and urban development. The plan clearly considered future growth and its resulting transportation needs. Three types of emissions were mapped from this plan. They were as follows: Figure H-1 shows carbon monoxide, Figure H-2 carbon dioxide, and Figure H-3 hydrocarbons. On each of the maps in this series one can recognize the corridor pattern of motor vehicle emissions as well as nodes of higher emission concentration and urban centers with extremely high pollutant emission levels.

3.2 CONTINUATION OF EXISTING TRENDS SITUATION

The alternative transportation situation is a continuation of the existing trends with minimum governmental planning control. This approach does not embody consistent regionwide policies for urban development or transportation planning, but rather, responds to the pressing and immediate needs as they are realized. When this system was mapped it showed a typical pattern of emissions ringing out from the main urban cores of Seattle and Tacoma to the peripheral suburbs. Because of considerations of computer funds, only one pollutant for this system was mapped.

This particular pollutant was carbon monoxide (CO) (Figure H-4). It was selected because of its relative importance and because it was quite similar to the other pollutant emission patterns.

3.3 DIFFERENCES BETWEEN THE TWO SITUATIONS

The next phase of the project was to look at the differences between the two transportation alternatives. Using Subroutine 15 of SYMAP[5] the two data sets were subtracted from each other, leaving positive and negative remainders. This data was then used to make two maps (Figure H-5 and Figure H-6) showing areas of either greater or lesser carbon monoxide levels as a result of the emissions from either one or the other transportation alternative.

3.3.1 Use of Difference Maps

Two maps are necessary for such a study because there are two different sets of data both starting at zero and "increasing" in opposite directions. In effect, the two maps show a continuous surface of data that meets at the zero value. For analytic purposes it was most desirable to show graphically both the positive values and the negative values as volume. Cartographic tradition has suggested that volume should be shown by an increasing scale of darkness, as is shown in the two maps. Thus, the technique of having two maps showing the different directions of the data was used.

When reproduction budgets permit, it is often of special visual clarity to superimpose these two maps with color separation prints so that the final composite map depicts one increasing scale in black and the opposite scale in some contrasting color.

3.3.2 Visual Analysis of the Difference Maps

Each map shows at least two things visually. The areas of darkest tone show where the differences are the greatest and thus articulate in rank order the areas where pollutant emissions from the alternative transportation situation are in excess of the one being examined. The white areas of the map designate where the emission impact of the alternative transportation situation is less than the one being studied.

By looking at the second data set one gets the impression that he is looking at an "opposite" map. Certain qualities of the map give this impression. The previously white area of the first map is now taken up by an increasing scale of dark zones, and the previously dark areas are now all white.

When we analyze the two difference maps we find immediately that System 32 emissions (Plan A: continuation of existing trends) significantly exceed System 35 emissions in the major urban areas and surrounding suburbs (Figure H-5). Moreover, when we visually examine the companion map (Figure H-6) where "Cities and Corridors" emissions exceed those associated with

the continuation of existing trends, we find the excess emissions relatively scattered throughout the region, removed from the urban cores, and of a lesser magnitude than in the first map (Figure H-5).

From a planning viewpoint we would intuitively predict that emissions would be lessened in the planned situation, but the computer mapping presentation provides a clear and pointed visual clarification of this intuitive impression and herein lies its "graphic" merit.

3.4 ANALYSIS POSSIBILITIES

The "analysis" merit, apart from the graphic one referred to above, is enhanced by an option in the latest version of the SYMAP program[6]. This option provides for the automatic calculation and tabular presentation of the percent of the study area contained in each data level. By knowing the total study area in square miles and selectively choosing the cutoff values for the data levels, it is possible to quickly and inexpensively determine the extent of the areas subjected to various emission levels. For the case of the difference maps, the extent of the areas where emissions are improved by a certain amount--for one alternative as compared to another--can immediately be determined by this option.

Very often we are interested in examining both a large scale region such as Puget Sound and one of its components, such as the city of Seattle, in more detail.

Merely by changing one option, or elective[7], in the map package, we can extract a small rectangular portion of the overall study area and enlarge it for more detailed examination[8]. We can proceed one step further and re-specify the outline of our study area as the limits of the city of Seattle, for example, (without changing any of the other SYMAP packages), utilize the option dealing with the percent of the study area in each level, and quickly and inexpensively portray in both graphical and tabular form motor vehicle emission implications to the city resulting from the alternative transportation situations.

To analyze the impact of the various transportation and urban development alternatives, we need to project the levels of air quality associated with each system. This would require data on meteorology and knowledge of stationary as well as motor vehicle emissions as input to an advection-diffusion model. Concentrations of air quality, rather than emissions per se, need to be compared in selecting the best system for implementation.

REFERENCES

(1) see: "Determining Air Pollutant Emissions from Transportation Systems" by J. A. Kurtzweg and D. W. Weig, USDHEW, PHS, NAPCA, Durham. Presented at the Symposium, "The Applications of Computers to the Problems of an Urban Society," sponsored by the Association for Computing Machinery, October 24, 1969, New York, N. Y. The data discussed by Messrs. Kurtzweg and Weig was used as the input for the mapping. Several of the maps shown in the Appendix on Computer Graphics were also published in the above paper.

(2) The constraint of 1000 data points per map originally resulted from computer storage capacity requirements of first and second generation hardware. Newer equipment (IBM System 360, CDC 6600, etc.) provide for sufficient core storage capacity so that SYMAP can be easily adapted to allow the running of maps with far more than 1000 data points (maps with 3100 data points have recently been produced at the Laboratory for Computer Graphics and Spatial Analysis). However, the greatly increased computer cost (both in terms of "charges" for additional core storage and running time to produce the map) do not warrant producing maps with greater than 1000 data points as a general practice.

(3) "Meld" is a data manipulating program written at the Laboratory for Computer Graphics and Spatial Analysis by John Goodrich and Kathleen Reine. It was developed specifically to handle the emissions data for this study. Its important features include the efficiency of data handling, aided by an in-core sorting routine adapted from a Harvard Share Library program. This routine is used to quickly rank order the x and y locations of all data points while automatically indexing the variables associated with each data point.

Another routine which is easily user-adapted creates whatever data grid is desired. With the data points already ordered by location and the grid established, it is possible to employ a very efficient routine for allocating each successive data point systematically

to the appropriate grid cell and averaging or aggregating the accompanying variables at the same time. Surprisingly little core storage is required, making the program very efficient for manipulating large quantities of data.

As with the numerous computer programs that were written during the project to meet specific data handling requirements, "Meld" has not been written up at this time, nor has a generalized version of the program been produced. As developed for the Puget Sound data, the program runs on an IBM 360/65 in 350 K taking 1 minute, 40 seconds CPU time to determine the grid system and to aggregate the data from 5600 locations into 930 grid cells. Input/output is by cards and/or tape. Once the grid had been determined for one transportation system, applying that grid to the data for an alternative system required changing only five cards in the program--this change could have been accomplished by a data statement or by reading in the necessary information.

(4) Various technical reports of the study--in particular, Volume Two, Report K-- deal with the steps involved in setting up the packages needed to produce maps of differing complexity. In the case of the Puget Sound Study, the Otolegends package was of sufficient detail to justify the coding of points with an electronic digitizer rather than by hand. The same was done with the outlines package although this could have been accomplished by hand.

The data point locations and accompanying values at over 5500 locations were originally provided on cards. The "Meld" program created the data point locations for the centroids of the approximately 1000 grid cells and the aggregated values associated with them. These were stored on tape (as well as on cards) for input to SYMAP.

(5) As described in Volume Two, Report K, Subroutine 15 of SYMAP, or FLEXIN, is the user-oriented routine which allows the manipulation of most of the packages (generally the values package so that data can be drawn from a data bank), and avoids the initial coding of all information in the standard form. Its use here was in creating the differences as values for the mapping, subtracting the two sets of carbon monoxide values for the alternative transportation situations.

(6) Version 6 of SYMAP (for the IBM System 360) contains this option as standard. The maps discussed in this report were produced before this version became operational.

(7) Elective 2, which specifies the extreme points (x and y coordinates of the upper left and lower right corners) to be included in the map produced.

(8) Examples of enlarging portions of a region for more detailed examination will be found in the report on the Boston Region Study, Volume Two, Report J.

APPENDIX

COMPUTER GRAPHICS

NOT REPRODUCIBLE

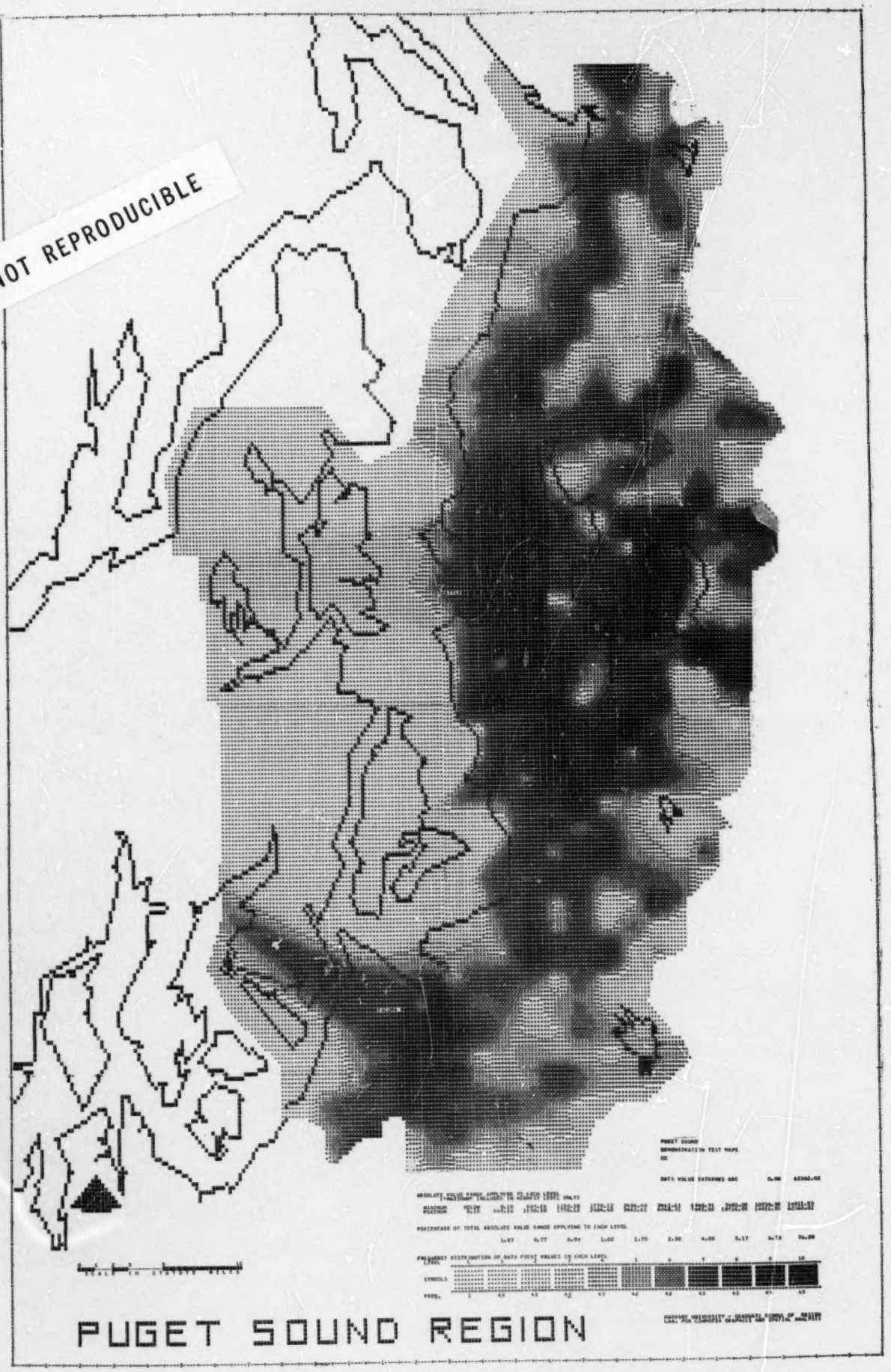

FIGURE H-1

PUGET SOUND REGION STUDY
Carbon Monoxide Motor Vehicle Emissions
Cities and Corridors Plan — System 35

NOT REPRODUCIBLE

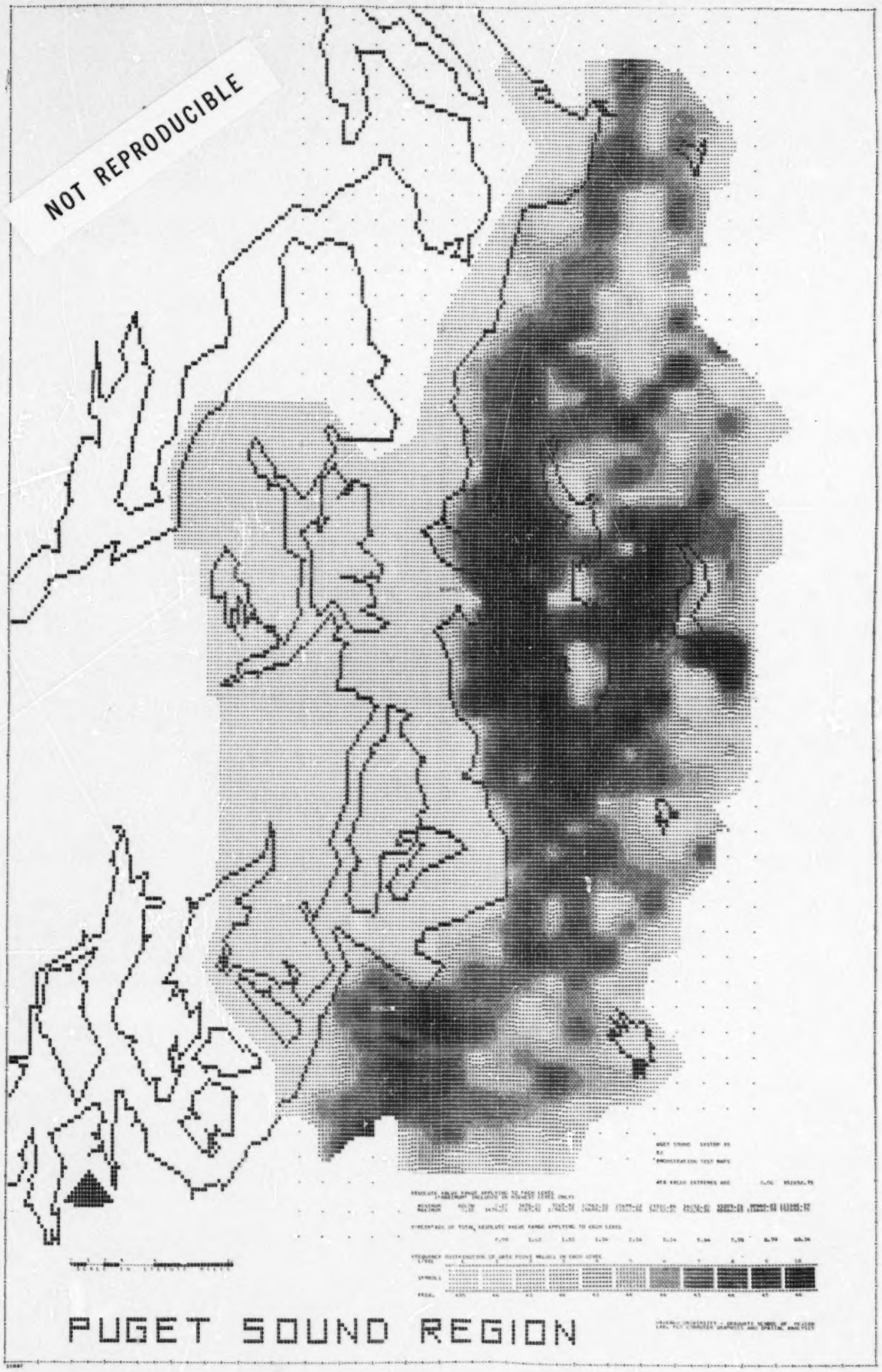

FIGURE H-2

PUGET SOUND REGION STUDY
Carbon Dioxide Motor Vehicle Emissions
Cities and Corridors Plan — System 35

NOT REPRODUCIBLE

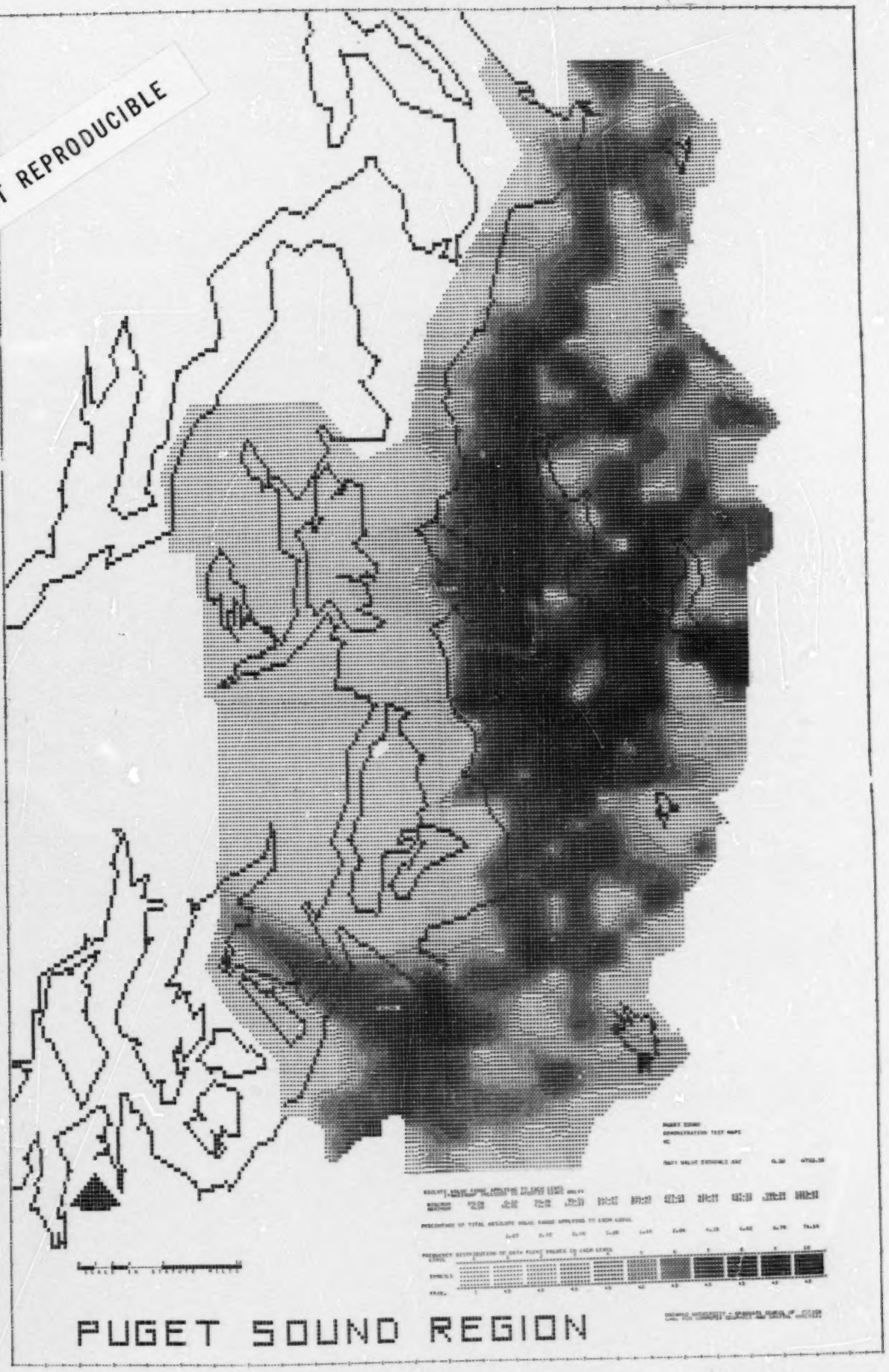

FIGURE H-3

PUGET SOUND REGION STUDY
Hydrocarbon Motor Vehicle Emissions
Cities and Corridors Plan — System 35

NOT REPRODUCIBLE

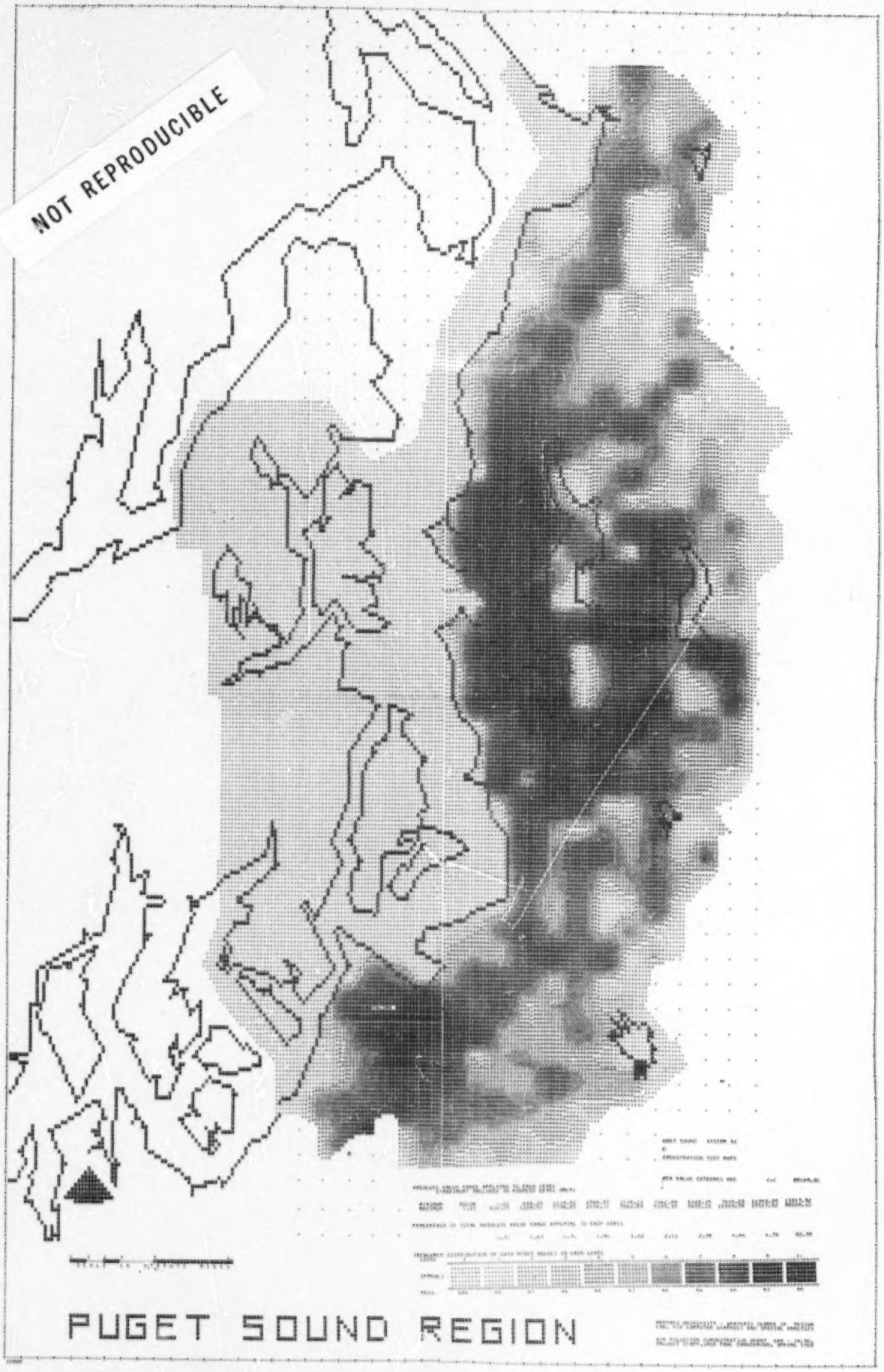

FIGURE H-4

PUGET SOUND REGION STUDY
Carbon Monoxide Motor Vehicle Emissions
Continuation of Existing Trends — System 32

NOT REPRODUCIBLE

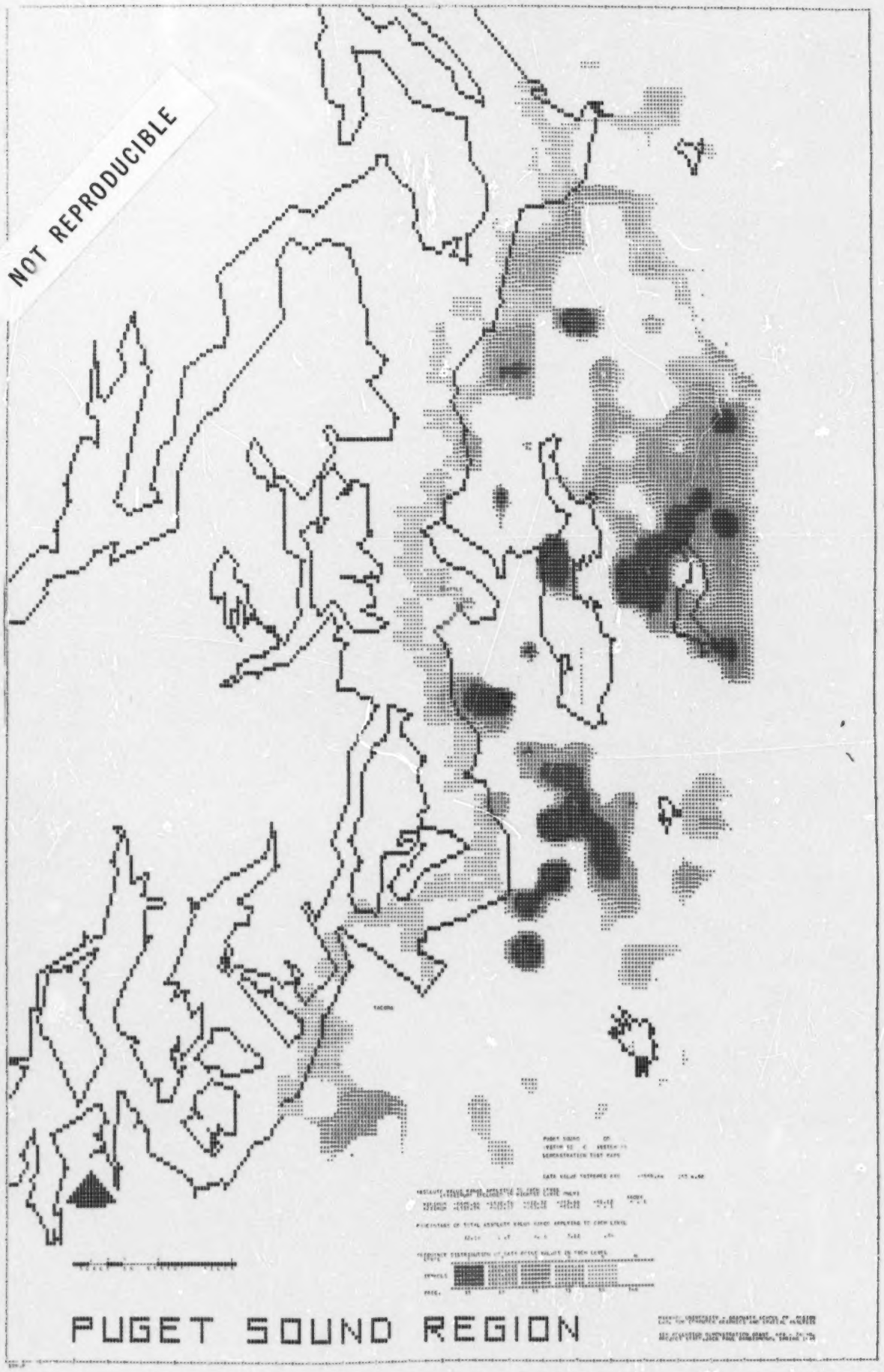

FIGURE H-5

PUGET SOUND REGION STUDY
Differences in Carbon Monoxide Motor Vehicle Emissions
System 35 Exceeds System 32

NOT REPRODUCIBLE

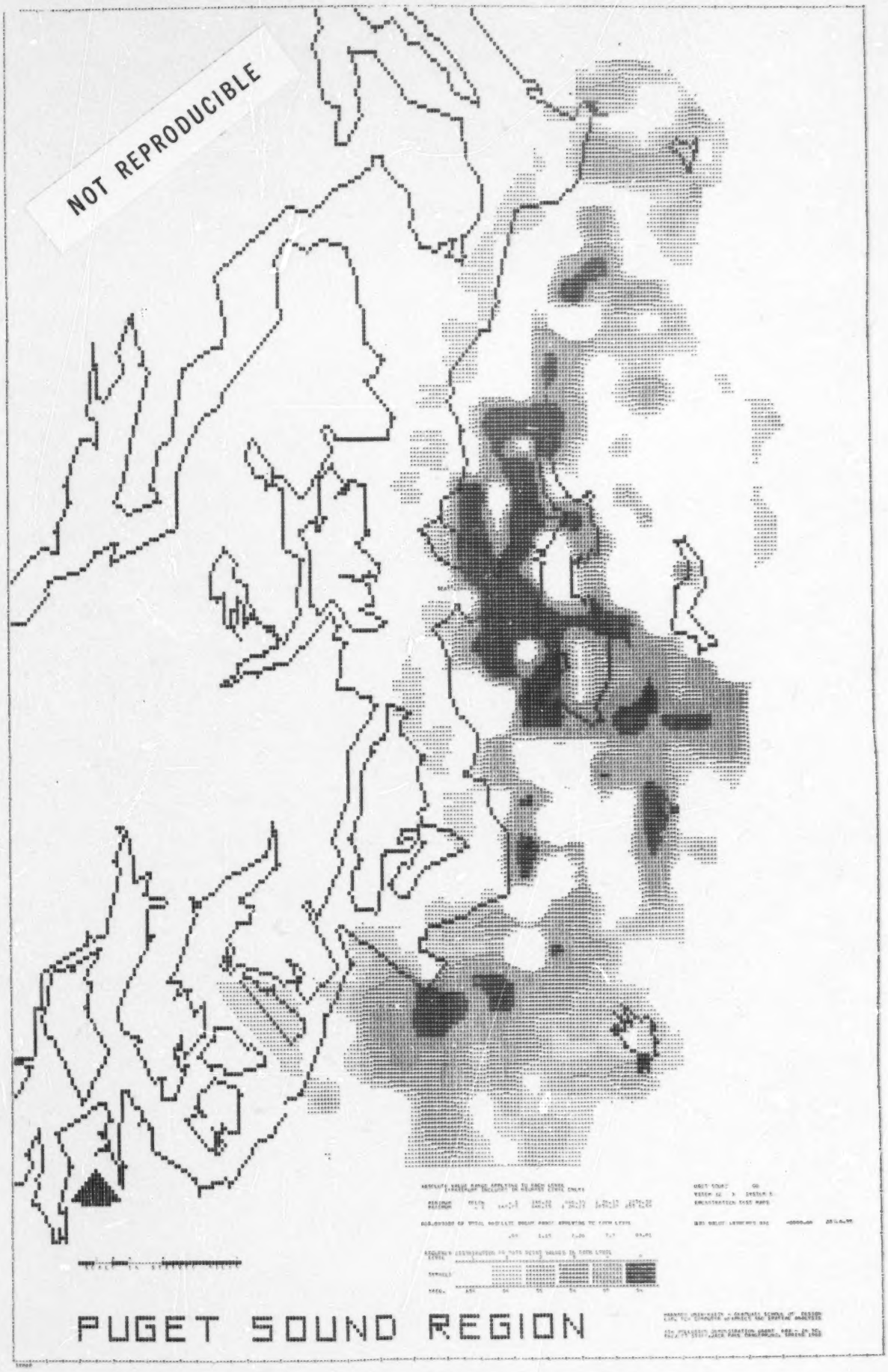

FIGURE H-6

PUGET SOUND REGION STUDY
Differences in Carbon Monoxide Motor Vehicle Emissions
System 32 Exceeds System 35